NASA TECHNICAL TRANSLATION NASA TT -20155

THE INFLUENCE OF FOREIGN PARTICLES ON BEARING METALS

Sanae Mori

(NASA-TT-20155) THE INFLUENCE OF FOREIGN PARTICLES ON BEARING METALS (NASA) 20 p CSCL 11F

N88-26454

Unclas
G3/26 0154068

Japan Society of Lubrication Engineers Journal, vol. 17, 1972, pp. 741-746

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 JUNE 1988

NASA

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TT-20155		

4. Title and Subtitle	5. Report Date
THE INFLUENCE OF FOREIGN PARTICLES ON BEARING METALS	JUNE 1988
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Sanae Mori	
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
National Aeronautics and Space Administration Washington, DC 20546	NASW-4307
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	translation
NASA - LEWIS RESEARCH CENTER	14. Sponsoring Agency Code

15. Supplementary Notes

Transl. from JAPANESE to ENGLISH. Japan Society of Lubrication Engineers Journal, vol. 17, 1972, pp. 741-746

Transl. by SCITRAN, Santa Barbara, CA 93150.

16. Abstract

Incidents relating to automobile engine bearings caused by foreign particles are discussed. Granular materials can cause cracks and wedges in soft bearing surfaces, leaving scratches in the bearing metals. 10 figures and 4 tables illustrate conclusions.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
	unclassified-unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
unclassified	unclassified	20	

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THE INFLUENCE OF FOREIGN PARTICLES ON BEARING METALS

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Sanae Mori

1. Introduction

Even in countries where the percentage of surface roads is high, as in England or the United States, the majority of incidents relating to automobile engine bearings are caused by foreign particles. Table 1 shows that while each company has different figures, the percentage of inciderts caused by foreign particles for all often exceed 30-40% [1,2,3].

2. The behavior of foreign particles

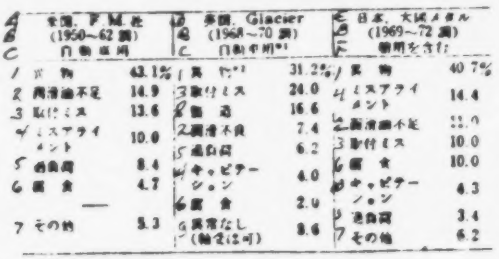
The behavior of foreign particles that move and flow in oil lines depends on the particle shape, size, quantity, hardness and relative weight.

Granular materials, such as sand, roll easily sometimes implanting themselves in cracks and wedges in soft bearing surfaces and sometimes leaving scratches in the bearing metals. Wedge shaped iron filings and flake shaped non-iron filings are drawn into the cracks and wedges, sometimes digging in and scratching in a circular direction, sometimes stabbing into the shaft and leaving relatively large ditch-like scratches.

It is natural that in these cases the scratch would be larger as the foreign particles get larger. It is usual that the smallest part (h_{min}) of the wedge crack of the bearing metal would be 0.001-0.020 mm and the largest part (h_{max}) would be 0.05-0.3 mm, and in general, an oil duct is provided for these parts. So the large foreign particles travel from the oil through the oil duct

*Numbers in margin indicate pagination of foreign text.

TABLE 1. Comparative percentages of the causes of incidence relating to bearing metals for the various companies



*1 22.6% were bearings for replacement.
*2 includes nitride iron from nitride shafts
A--America, Ford Motor Co.; B--(1950-62 models); C--automobile; D--England, Glacier; B--(1968-70 models); C--automobile 1*; E--Japan, Daido Metal; B--(1969-72 models); F--including ships; 1--foreign particles; 2--shortage of lubricant; 3--installation error; 4--misalignment; 5--overload; 6--decay; 7--other; 8--makeup; 9--nothing out of the ordinary (possibly bearing metals); 10--cavitation

entering the oil drain or the oil plug. These particles affect the discharge of oil and the rotation of the shaft and have a chance of working into the oil drain, oil plug and can flow or rotate along in the direction of the edge of the shaft or in a circular direction toward the edge.

When we test it by comparison of plated bearing metals of copper lead and unplated aluminum metals by adding large quantities of foreign particles, the plated bearings burned up but the aluminum ones survived. It is thought that this is because the aluminum, having a small h_{min}, checked the foreign particles before h_{min}, and the soft copper lead surface plating drew in the foreign particles.

The engine bearings are supplied with oil by way of the shaft center oil line from the oil drain of the main bearing in the direction of the edge bearings. There is, in many cases, no oil drain provided for the edge bearings. Therefore, the foreign particles in the oil, even though they build up along with the centrifugal force at the surface of the bearing, do not easily enter the cracks in the bearing metal.

In this manner foreign particles cannot easily enter the main bearings and the situation plays a role exactly like that of a filter. The foreign particle scratches in the edge bearings are few.

The thickness of the foreign particles that are seen in this kind of bearing metal would be expected to be up to 0.3 mm but the size surpassed that to 0.5 to 1.1 mm [3].

The foreign particles that flow in and out, while leaving tracks like those of an inflow or an outflow, corrode the surface of the bearing metals [5]. Even when they are arrested by blockage of the oil filter, they go so far as to bypass the blockage directly corroding the bearing metals.

As the bearing metals get harder they increasingly scratch and dig into the bearings. Sand, which is hard and brittle, easily breaks and iron flakes which are viscous and strong become condensed [3]. The damaged flakes of nitriding steel or carbonized bearings that are soft dig into the bearing metal side, and they create friction with high speed bearings, thus creating heat. They also add smoke and cause a hardening action, thus becoming a major cause of damage. Even materials with a soft composition, such as fibrous materials or sludge, can gain entry through narrow oil cracks or a blockage in the oil filter. Aluminum flakes that have a good flexibility easily become flaky and do not easily burn. Especially if there is a temporary digging in on the surface of the aluminum bearings, the foreign particles fly out along with the action of the bearing center and easily cause pointed scratches. In the initial period of the pointed scratches in soft white surfaces or in plated surfaces, there are a large number of miniscule green-shaped (illegible) or fusions. In the under flow it is compressed and squeezed, cooled, hardened and often disbursed spottily onto the cracks and edges where there is oil build-up.

The foreign particles, which collect easily in holes or at

TABLE 2. Comparative percentages of types of foreign particles in bearing metals

iron	80.5%:	a large quantity from cast iron (the majority are rice sized particles
sand	9 0 :	a large quantity is cast sand
aluminum	3.4 :	a large quantity are piston flakes
copper	1.1 :	
other	6.0 :	

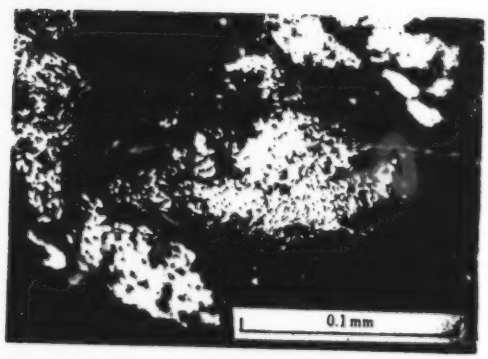


Figure 1. Cast iron type foreign particles

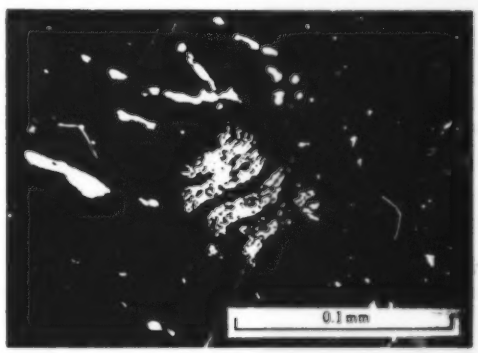


Figure 2. Light steel type foreign particles

tank bottoms are in proportion to their relative weight, make it /38
as far as the middle of the crank pin oil line and through oil flow, centrifugal force, and the effect of the cracks and wedges, leave circle-shaped marks on the center parts of the extreme bearings.

3. Types of foreign particles

In the contamination of oil, other factors besides foreign particles, such as oil oxidation or fatigue, can be included. According to Glacier Company (hereafter referred to as G. Co.), the contamination of oil can be classified as follows:

(1) Foreign particles existing inside: In spite of the best efforts of the engine makers, inside new or overhauled engines there are foreign particles which have not been eliminated. These foreign particles are sand that is washed off of cast parts with lubrication or metal flakes and pieces of dust that are not eliminated during engine production or assembly.

(2) Foreign particles brought by air: Extant in the atmosphere are sand and dust that enter through air intakes and outlets and other such places, some quantity of this ends up entering the lubricant.

(3) Products of combustion and the fatigue of oil due to driving wear: Sooty carbon, sulphuric acid and other acids, gummy substances, moisture and oxides are produced.

(4) Dust from wear: From surfaces that have continuous rotation, generally as a result of friction wear, dust will appear. This can be seen at such places as piston rings which rotate on the outer surface of the cylinder.

(5) Foreign particles introduced through fueling: When dirty oil is put into the engine. An example of the size ratio of the various foreign particles in lubricants is as follows:

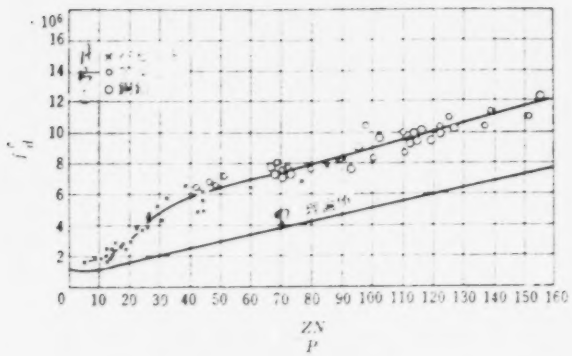


Figure 3. Friction curve of Babbitt, aluminum, copper lead bearing metals in the case of pure oil

A--Babbitt; B--aluminum; C--copper lead; D--theoretical value

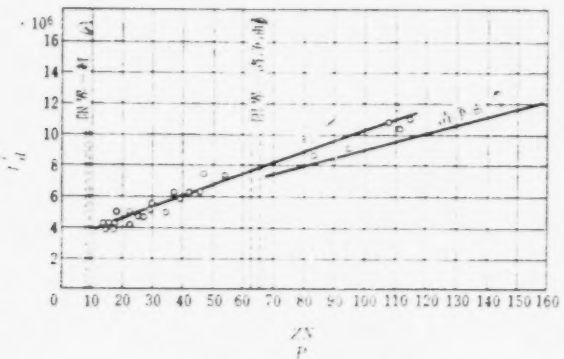


Figure 4. Friction curve for copper lead bearing metals as opposed to oil mixed with 1/2 g/gal of rouge

A--limit-rouge; B--limit-pure oil; C--rouge; D--pure oil

Foreign particle size μm	<2 ~1	5>
Weight ratio %	92	7 1

According to experience, we must change the oil when the percentage of dirt reaches about 2%. This, however, is only applicable to oil which has not become thin due to the presence of fuel, that does not contain excessive amounts of water and that has not seen the exhaustion of its oil additives through wear and tear [2].

For the tests carried out by this company (from June 1969

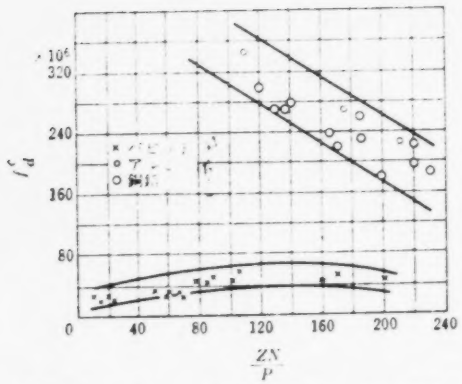


Figure 5. Friction curve for Babbitt aluminum copper bearing metals as opposed to oil with 1/2 g/gal of 22 μm corundum mixed.
A--Babbitt; B--aluminum; C--copper lead

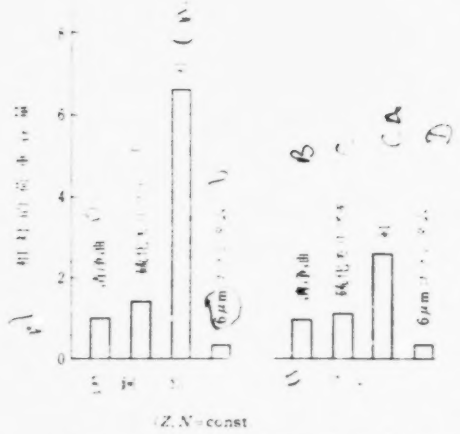


Figure 6. Relative load weight and volume of copper metals.
A--relative load weight of copper metals; B--pure oil; C--molybdenum sulphide; CA--rouge; D--6 μm corundum; E--lead; F--aluminum

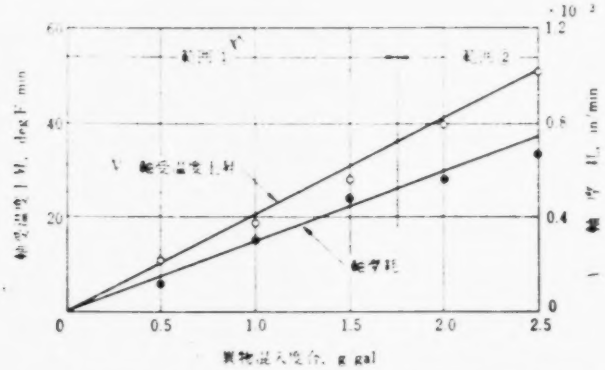


Figure 7. Relationship of the mixture of foreign particles and temperature rise bearing metal, friction wear in bearing metals that occur in 60øx37 Durex 160A
A--area; B--rise in temperature bearing metals; C--friction wear on bearing; D--mixture of foreign particles; E--rise in bearing metal temperature; F--friction wear on the bearing

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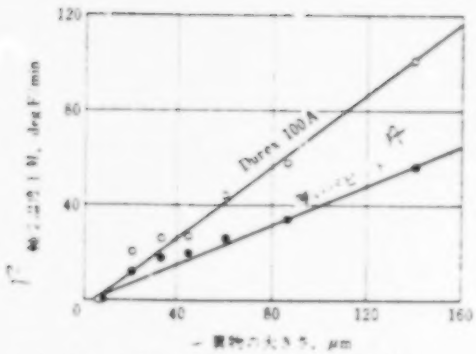

Figure 8. Relationship between the foreign particle size and the rise in temperature.
A--thick Babbitt; B--rise in bearing metal temperature; C--foreign particle size

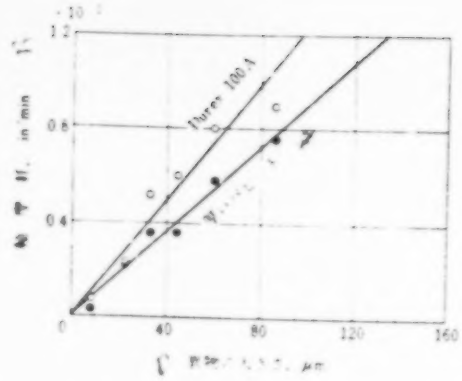

Figure 9. Relationship between foreign particle size and the friction wear of the bearing.
A--thick Babbitt; B--friction wear on the bearing; C--rise in bearing temperature; D--foreign particle size

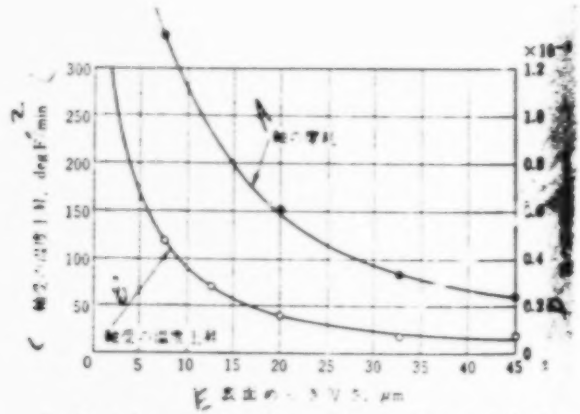

Figure 10. Relationship between the thickness of the surface plating of 60øx37 copper bearing metals and the rise in bearing temperature at the time of mixing foreign particles and the friction wear on the bearing.
A--friction wear on the bearing; B,C--rise in bearing temperature; D--friction wear on the bearing; E--thickness on the surface plating

through January 1972, refer to Table 1). Most of the foreign particle percentages are seen in Table 2. The iron content is shown as 80.5% and is compared to 70% in the case of F.M. Company.

In Figures 1 and 2, we have the microscopic photographs of the foreign particles. Figure 1 shows the pear-like formation and is thought to be a crankcase shaving at FC20 grade. Figure 2 is a soft steel drawing material and is thought to be a wire brush flake [3].

4. Effect of foreign particles

4.1 The friction coefficient and the volume of the bearing metals (ZN/P) [6]

According to ASME, if the foreign particle size turns upward more than the size of h_{min}, it is natural that the oil membrane lubricant will be affected.

The friction coefficient curve at the area of the oil membrane lubricant in pure oil is, in spite of the addition of the roughness problem source, the same for aluminum Babbit and copper lead as seen in Figure 3.

As the roughness is smoothed out there is no metal contact up to a small h_{min} and it is learned that ZN/P_{min} becomes smaller. Hence, improvement of the roughness of the surface is thought to increase the ability of the bearing metals (lessening the $(ZN/P_{min}$ creating proper foreign particles that will not impede the flow of oil. In Figure 4 we show the case in which 1/2 g-gal of large 1 µm of rouge is added to the oil. The friction coefficient lowered on a large scale but in essence it was the same as the oil membrane lubricant using pure oil. The improvement of surface roughness in this case was for the shaft from 6-8 to 4-6, for aluminum, it was 20-22 to 16-20, and for copper lead it was 47-53 to 35-40 µ in rms.

Also, even when 1/2 gallon of large 39 μm of molybdenum sulphide was placed in the oil, there was not much change in Babbitt, but for aluminum and copper lead, the change was quite noticeable.

The friction coefficient (fc/d) of aluminum and 6 μm when half a gallon of 6 μm corundum was put in was 4 times that of pure oil. Because of high temperature caused by this kind of large friction coefficient, the ZN/P_{min} went over 100.

In Figure 5 we show the situation when 22 μm corundum is used. We want to draw attention to the fact that ZN/P and aluminum both show about the same friction. On the side where the ZN/P is large, the friction is lower due to the increase in the thickness of the oil membrane. In a situation where the thickness of the oil membrane is greater than the dimension of the foreign particle, we see friction extremely close to that of the pure oil (Babbitt's friction when compared with copper lead aluminum is far smaller).

When using corundum which is larger than the thickness of the oil membrane, the friction wear was extremely fast. For both types of bearing metal materials the shaft friction wear was faster. Another effect of the 22 μm corundum was the roughness of the surface of the bearing metal. In other words, the surface of the 20-22 μ in rms aluminum was through the 22 μm corundum increased to 50-55 μ in rms.

Finally, the soft molybdenum sulphide improved the fire resistancy and had the effect of lowering the ZN/P_{min} (raise the bearing volume, this is separate from fatigue resistance characteristics). (Refer to Figure 6). Even if small amounts of hard or sharp formed particles enter, the wear friction is fast. With aluminum or copper lead that is harder than Dabbit it is important to use a good filter [6].

4.2 Temperature rise, friction wear and the quality of bearing metal materials [4] /744

The Roach test was carried out with the Underwood movement load test device (centrifugal force). It was done with a wave-like load sine of 210 kg/cm^2 at 4000 rpm, a shaft diameter of 60 ø, a bearing width of 3 and employed a FC 26-29 smoke inserting grinding sleeve. The pure oil was drawn from a tank and the oil with foreign particles mixed in was introduced from a separate mix tank.

4.2.1 Triple layer bearing metals

In Figure 7 are the results of the mixing of the 28 um aluminum crystals as opposed to Durex 100 A (porous Cu-Ni fueling with babbitt (Pb 92.5, Sn 4, Sb 3.5) 50-75 um casting). It was ascertained that as opposed to the saturation of the temperature rise of area 1 of Figure 7, after area 2 shows an intense peak (it is thought there is flow movement at a limited area) its stabilized.

Durex 100 A is a copy 60 um class thin babbitt. In Figures 8, 9 we see the results of a comparision with this of the same babbitt made up of a thickness of 0.8 mm. The size of the aluminum was 6-140 um and we mixed in 1 g/gal (SAE 30) and made the comparison. Temperature rise and friction wear went up as the babbitt got thinner and was approximately proportional to the size of the aluminum. In Figure 10 are the results of the thickness of the plating and the lead on the copper bearing metal (93 Pb, 7 Sn). We learn that there is a result at 20 (10-30) um on the temperature rise and friction wear.

It is clear that the abrasion characteristics are affected by the abrasion characteristics of the base. Figure 3 gives an example of a comparison of a plated copper and plated Si-Cd aluminum. The foreign particles in the former were 28 um, the latter

TABLE 3. Results of the base and surface plating

surface plating thickness, μm	rise in bearing temperature, deg F/min	
	copper base	aluminum base
0	3300	280
10	85	51
20	40	41

TABLE 4. Result of abrasion tests on various materials

No.	Materials	A	B *2
1	thick lead Babbitt (thickness 0.8mm) *1	124	100
2	Durex 100A	100	100
3	copper (unoxidized)	0.5	
4	copper grid (pitch 48)	32	50
5	copper +45μm Pb-Sn alloy	100	130
6	copper +33μm Pb-Sn alloy	100	117
7	copper +20μm Pb-Sn alloy	50	50
8	copper +13μm Pb-Sn alloy	32	43
9	copper + 8μm Pb-Sn alloy	17	22
10	copper lead (60Cu, 40Pb)	7.5	20
11	copper lead (65Cu, 35Pb)	5.5	33
12	copper lead (70Cu, 30Pb)	5.0	15
13	copper lead tin (75Cu,24.5Pb, 0.25Sn)	4.0	23
14	copper lead tin +25μm, Pb-Sn alloy	69	68
15	aluminum (95Al, 4Si, 1Cd)	10	37
16	aluminum +20μm Pb-Sn alloy	68	89
17	aluminum +10μm Pb-Sn alloy	55	78

*1 The value of A is 0.05 lead Babbitt 100, 0.13 tin Babbitt 145 in the other ROACH paper [9].

*2 The comparative value was set in the case of Durex 100A at 100 and the temperature rise at the time of foreign particle mixture at A and the friction wear of the bearing at B.

was 32 μm and there was little exception or gap in the conditions. When the plating thickness becomes half, with copper, the temperature rise is 110%, but with aluminum it does not go beyond 25%. It becomes clear that this comes along with thinning of the plate and its approach to the abrasive characteristics of the base.

4.2.2 Gridded metal /145

Gridded metal is that which has many small pockets of copper or silver base filled with lead or babbitt. When the shaft rotates foreign particles dig into the pockets and make long pulling scratches in the surface. Confirming the abrasion and iron content at H_v 44 with a Cu base, if the foreign particles are not smaller than the pockets, we learn that they collect in the babbitt part of the pocket. In a situation with the same iron content we see it in the H_v 43 of a silver base pocket (babbitt) but when we dull the silver to H_v 32, we do not see an accumulation at the abrasion iron content pocket (babbitt) part and they are distributed at random on the surface of the bearing. In this manner the gridded metals improve the abrasion characteristics of bearing metals but the size of the foreign particles that dig in are limited by the size of the pocket and if the pocket is larger, the resistance to the fatigue drops. The surface plating has a similar abrasion characteristic but the foreign particles which dig in vary according to the plate thickness.

4.2.3 Oil drain

Because the oil drain normally lowers the h_{min}, it would be thought of as on the dangerous side for foreign particles, but rather it is the opposite. This is because oil containing foreign particles is flowing through the oil drain and there is a discharge of the foreign particles through a h_{max} part that is adequately large and the cooling is complete. It is important to note the rise in temperature of the bearing metals and the slowing of rotation speed by the foreign particles. In order to do this, because of the operating point of the bearing descends in the

downward direction of the ZN/P curve, the h_{min} goes down and in addition becomes an (illegible) of the foreign particle. Therefore, in order to maintain the thickness of the oil membrane, it is important to keep the operating point at ZN/P curve in an upward direction as much as possible and it will be achieved with the flow quantity kept as large as possible.

4.2.4 Abrasion characteristics of various types of materials

Table 4 shows the results of scratch tests on the various types of materials carried out in ideal conditions for load weight and speed, etc. In the table we compare the abrasion at two standards, A and B.

(1) A is shown with the temperature rise at the time of introduction of oil mixed with foreign particles. Normally, it is a comparative appraisal with the same conditions as those of Durex 100 A.

(2) B is expressed by the percentage of friction wear on the bearings at the time of introduction of the oil mixed with foreign particles.

This method of appraisal is the most convenient and we approve of it because as the numbers get higher it becomes an example of the improvement of the abrasion characteristics and because the size and quantity of previous foreign particles have a porportional relationship to the rise in temperature and the bearing friction wear.

The area of most interest in Table 4 is the abrasion characteristics of the surface layer and we want to compare, for example, nos. 3 and 7, 13, 14, and nos. 15 and 16. Next, it is established with the inter-relatedness of the temperature rise and the bearing friction wear parts (the figure is abbreviated) that for all materials the former and the latter show a linear relationship

TABLE 5. Change in oil temperature and pressure at the time of mixing the foreign particles in the engine

progress time, min	oil pressure psi	oil temperature, °F
0 (at the commence of adding foreign particles and oil)	52	210
1 (at the conclusion of adding foreign particles and oil)	32	215
2	30	230
3	28	240
4	27.5	255
5	26	260
6	25	265
7	18	285
8	12	295
8.5 (engine shutoff)	7.5	295+

and at the same time the size and quantity of the foreign particles extend to a considerable area [4].

5. Tests of the foreign particles

5.1 Engine tests [7]

Here we show an example of a test where foreign particles were purposely placed into an engine's oil.

In Thill's paper, after running the engine at a hot idle at 1000 rpm for 15 minutes, a slowly raise it to a 90% load at 4000 rpm . The oil was adjusted to 210°F (100°C) and the pressure of the oil was at 52 psi.

The results at these conditions of the introduction of oil mixed with iron is shown in Figure 5. After 8.5 minutes, the entire main bearing was destroyed. The central bearing and lower sides together over-heated considerably and burned up.

All of the other main bearings undersides were scratched and injured at the circular drain part. In the middle of the plated surface at the upper side we could see (illegible) foreign part abrasion. As for the extreme edge bearings, the number 2 on the right side and the number 6 on the left were horrible, but both were contacting at the top of the same crank pin (V type engine). The maximum friction wear for the number 2 crank pin was at 0.53 mm and for the central main bearing, it was 0.33 mm. The weight loss for the whole bearing was 4.1%.

For the next test the oil pressure was lowered to 38 psi, the temperature was raised to 240°F and oil mixed with iron parts was introduced. After that, the fall in oil pressure and the rise in oil temperature was even faster than that in the initial test. Both the large edge bearing and the main bearing became even more horribly wrecked faster than in the first test and like the engine in 3.5 minutes, all of the bearings were ruined.

A large iron content does a fine job of wrecking havoc or over heating and firing the bearings that are made of copper alloy. Fire door charred bearing surfaces resemble the situation caused by bad lubrication coming from bad function of oil pumps or oil pressure relief valves, low oil, lack of oil ventilation, or thinning of oil. Therefore, it should be asked if copper alloy bearings or other high load use bearings burning up or showing extreme friction wear is not because of hard foreign particles.

5.2 Identification of foreign particles

It has often been possible by tightly wrapping and closely examining the surfaces of bearing that have been abraded by foreign particles, to detect clearly sand or iron, etc., and to ascertain the source of the foreign particles.

Establishing the hardness by classification of form and color of the foreign particles as well as the magnetic reaction of the iron flakes in the cuttings of the bearing surface are at present

the easiest means for differentiating the foreign particles.

For the establishment of the iron filings, the ferroxyl test used in the plating pinhole test is the best. G. Co. called this iron printing [8]. Fluid that has reacted with iron on filter paper is applied to the surface of the bearing metals. The area that was abraded by iron filaments gave a blue reaction. In the case of aluminum or zinc iron base alloys, in order to get a reaction out of the iron a direct current was applied to the space between the bearing surface and the filter paper.

5.3 Filter

G. Co. highly praised the centrifugal filter, the test results are as follows:

(1) There was a marked difference seen between the results of the composite foreign particle extraction of the centrifugal filter (G. Co. G.F. 1) and those of the paper element or full flow pack felt element.

(2) The comparative ratio of large damaging foreign particles for the oil filtered through the centrifugal filters was less than any of the oil filtered through pack filters.

(3) In comparison to any of the pack filters, at a good service rate of 1/5, the quantity of foreign particles extracted during this long period was 10 times that which was extracted by the pack filter in a short life span.

6. Conclusion

Concerning the prevention of the mixing of foreign particles in lubricants, it is important to consider, 1) cleanliness, 2) flushing, 3) filter, 4) oil change. In particular, it is noted that by means of a waste disposal drain or by means of surface

parts matching bearings metals that go in the direction of the shaft, that there is a plan by which waves can be passed (also this is useful for cooling).

Along with expressing our thanks to the Glacier Metal Co., we would like to close this article by expressing our respect for the ample contribution of those before us.

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